

## LASER OPTICAL DISK POSITION ENCODER WITH ACTIVE HEADS

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## ABSTRACT

An angular position encoder is discussed that minimizes the effects of eccentricity and other misalignments between the disk and the read stations by employing heads with beam steering optics that actively track the disk in directions along the disk radius and normal to its surface. The device adapts features prevalent in optical disk technology toward the application of angular position sensing.

## INTRODUCTION

In the following discussion, brief descriptions of both conventional encoder technology and optical disk technology are provided. A hybrid encoder is then considered which combines these two technologies. Apart from higher resolution, numerous other advantages are foreseen for this hybrid device.

## CONVENTIONAL OPTICAL ENCODERS

Physical Description and Operation

A conventional rotary optical encoder consists of the elements depicted in Figure 1. Photodetectors are used to sense the motion of a disk which has been affixed to a shaft whose orientation is to be monitored. Encoded on the surface of this transparent disk is a series of dark lines running in the radial direction. These lines form a circular track bounded by an inner and outer radius. A light source is placed on the opposite side of the disk. As the shaft rotates, the photo detectors sense the changing illumination as a series of pulses. In order to collimate the light, a mask and a pair of lenses are generally employed.

The encoder just described is of the incremental type. It simply counts pulses from some reference orientation and computes the angular rotation in proportion to the number of counts registered. Multiple tracks or read stations placed out of phase with respect to one another are used to sense direction of rotation. Phasing of read stations also generates phased wave forms which can be interpolated electronically to yield higher resolutions.

Error Sources

Several factors affecting the performance of encoders have already been alluded to. Eccentric mounting of the disk will result in a cyclical variation in the location of the track with respect to the read station. The radius at which counts are being taken varies accordingly. Since the angular position is calculated by assuming a fixed radial distance in combination with the observed arc length, an angular error results.

Similar behavior results when there is radial play at the interface between the shaft and the bearing bore. Since the shaft, and the affixed disk, are free to wander, the radial position of the track relative to the read station varies in an unpredictable fashion. Once again angular errors result.

Axial play can cause problems as well. Because of the optical arrangement typically used, the distance between the disk and the emitter is critical, particularly in high resolution devices. Variations in this distance cause the illumination passing through the disk to vary even when the disk is not rotating. These variations can confuse the counter. Disk warp can introduce the same kinds of effects.

Two other parameters which encoders are sensitive to are disk to shaft perpendicularity and the circularity

of the track on the disk. These and the aforementioned error sources are strictly mechanical in nature. Errors can be introduced by thermal or electrical effects as well, but they will not be addressed here. Multiple read stations evenly spaced around the disk are often used in the higher resolution devices to allow averaging out of disk wobble and warp.

### Encoder Constructions

Encoders are available as either pre-assembled units or modular kits. Pre-assembled units contain all components internally. Each unit includes its own shaft to which the disk is affixed internally. At installation, the shaft of interest is attached to the encoder shaft via a shaft coupling, and the body of the encoder is bolted to the shaft housing.

Modular encoders consist of two independent pieces: the disk, and the encoder body which includes the optics. In this case, the disk is coupled to the subject shaft independent of the encoder body. The encoder body is then placed over top of the disk. Generally some provision is provided for adjusting the relative position of the encoder body with respect to the disk. The ability to align these components relative to one another directly influences the accuracy and the resolution achievable.

The advantage of the preassembled units is that the alignment of the optics with respect to disk is maintained by a bearing internal to the encoder. The manufacturer has the tools to ensure that this alignment meets tight tolerances. The alignment of the encoder shaft to the subject shaft, however, is generally the responsibility of the user. Care must be taken not only to align the encoder shaft to the subject shaft properly, but to ensure that no significant loads are passed through the encoder bearings due to relative motion of the two shafts. Such loads may introduce misalignment, or worse yet, lead to deformation of the disk and other anomalies. Flexible couplings have been developed to address this problem.

High resolution encoders have smaller optical paths which are more easily fouled by contaminants. It is impractical to allow assembly of these encoders by the end user in an uncontrolled environment. Pre-assembled units come sealed from the factory and are more resistant to contaminants than the modular types.

Modular encoders offer the advantage of being relatively inexpensive, and insensitive to external loads because they employ no internal bearings. Since they employ no additional bearings, one may argue that they are inherently more reliable. They also require no internal lubrication which is an important plus for applications in clean or low pressure environments. The chief disadvantage of these encoders is that the alignment of the encoder body relative to the disk is the user's responsibility. Accordingly, modular encoders are not used in high resolution applications [1].

## **OPTICAL DISK TECHNOLOGY**

Optical disk technology involves the storage and retrieval of data from a disk through the use of lasers. An embodiment of this technology with which most persons are familiar is Compact Disc, or CD, technology. Drives which handle optical disks are currently being sold as computer peripherals. The key selling point of these devices with respect to competing technologies in the mass storage market is the high density to which information can be stored. On a standard CD one bit occupies a spot only 0.5 microns (0.00002") in diameter. These bits, or pits, are burned into with a low power laser while the disk is rotating. This "burning in" of data constitutes the process of recording. The laser is pulsed appropriately to lay a stream of pits down in either a spiral track or a series of concentric tracks. Once the pattern has been burned into the disk, its entire surface is coated with a thin metallic deposition. Thus, the bottoms of the pits as well as the regions between pits (referred to as lands) have nearly the same reflectivity.

The principles of interferometry are applied in order to read the disk. The power to the laser is reduced such that it acts only as an illuminator. As the disk rotates, the light from the laser is focused via a movable objective lens onto a particular track. Variations in reflectivity occur at the transitions between pits and lands as a result of constructive interference, and these variations are sensed by the photodetector. Figure 2 depicts

the arrangement of components within a typical read station.

In order to keep the beam focused to the required degree, the read station used in an optical disk drive is equipped with servo controlled actuators. One of these moves the objective lens of the read head vertically to control focus and thereby accommodate disk warp. In order to accommodate disk wobble, a second actuator moves the objective laterally to maintain view of the track of interest at all times.

The feedback required to achieve this closed loop actuation is provided by the photodetector. The photodetector typically consists of a four element photodiode array. An amorphous objective lens is also used. When the beam is properly focused, the reflected light forms a circle on the array, equally illuminating all elements. As the disk moves out of focus, the beam rotates and deforms into an elliptical shape. This results in an imbalance in the illumination of the array elements. If the disk is too far away, the ellipse will form along one diagonal, and if it is too close it will form along the other.

Tracking information may be obtained by monitoring the signals on adjacent elements in the photodetector array. As the beam drifts off track it encounters the transition between pit and land. The resulting constructive interference causes a decrease in illumination over some of the detector array elements. The imbalance in the signals received from the elements is used to generate an appropriate servo signal.

More sophisticated tracking approaches are often used. In the three beam method, two beams are split off the main beam by using a diffraction grating. The grating is rotated out of plane such that these flanking beams strike the disk on opposite sides of the track and fore and aft of the main beam. Two additional elements are incorporated into the photodetector array to monitor the intensity of the flanking beams. Once again, appropriate servo signals are generated by comparing array element illumination signals.

The active focus and tracking actuators not only accommodate warp and wobble, but also make the device insensitive to vibration. The actuators are simple voice coil motors in which the objective is attached to a movable bobbin. This bobbin reacts to magnetic field variations in the surrounding control coils. It is physically connected to the surrounding structure by a spring metal diaphragm. There are no wear surfaces within the actuator.

Concerns about dust and contaminants blocking the field of view of the laser are resolved in the following manner. The information layer is actually imbedded in the disk as indicated in Figure 3. A lacquer coating protects this information layer. The optics within the read head are designed such that the output beam strikes the disk surface over a relatively large area about 0.7 mm (0.027") in diameter. As a result of the lacquer's relative index of refraction, the beam converges rapidly inside the disk to a spot only 1.0 micron in diameter. Thus, a particle on the surface would have to be quite large to interrupt the beam. In order to handle the eventuality of beam blockage, the data encoded on an optical disk is usually laid out such that the input data can be reconstructed despite the loss of a bit [2].

## **A HYBRID ENCODER**

### **Physical Description**

At NASA's Goddard Space Flight Center, a hybrid encoder is being developed which adapts the advantages of optical disk technology toward the problem of shaft orientation sensing. This hybrid encoder employs the optical approach and disk construction of optical disk technology. Potential applications include high resolution scanning instruments which require long life such as those to be employed on the EOS Platform. An isometric view of the hybrid encoder is provided in Figure 4. The read stations used are identical to those found in optical disk drives. The tracking strategy and the disk pattern employed, however, are designed to address the particular concerns of angular position sensing.

In an optical disk, the proximity of the pits to one another is limited by manufacturing process considerations. There are regions between pits of greater span than the diameter of the light beam. As the

main beam passes through these regions, the illumination on all photodetector array elements is the same and no useful feedback is provided from which to derive radial position. For a constantly spinning disk, this is not a problem as a pit soon comes into view, and the necessary feedback is made available. However, difficulty is encountered if it is desired to maintain head to disk alignment when the disk is stationary. There is a good probability that the disk will be oriented such that there are no pits within the field of view of the beam. Since no feedback is provided, motion of the disk cannot be observed. This is untenable in the encoder application because the very purpose of the device is to detect motion.

In order to alleviate this problem, a special disk pattern has been proposed for use in conjunction with the three beam tracking method. The pits are sized and located such that a pit is always visible in either the main beam or the flanking beams. Track-to-track spacing and the orientation of the diffraction grating are selected such that, should the main beam be off track, at least one of the flanking beams intercepts a pit regardless of the relative alignment of pits between tracks.

In order to allow for acquisition of a common track by beams from multiple heads, regardless of their initial radial positions, the arrangement of tracks depicted in Figures 5a and 5b is used. Two guard bands define a region of data tracks consisting of pits spaced at even intervals. The number of intervals is fewest near the guard bands and greatest along a central target track.

### Operation

At setup the heads are aligned over the region defined by the guard bands. The disk is rotated at a constant rate, and the servos are activated for each head. Each head acquires the nearest track and identifies the frequency of the signal fluctuations received. The beam is then moved over one track pitch, and the frequency associated with the adjacent track is identified. By comparing frequencies, the read station determines whether it is moving toward or away from the track having the highest frequency (the target track). Once the servos have locked onto the target track, the track radius is fixed, known and identical for all read stations. Since the read station moves with the track, the radius upon which angular calculations are based does not vary as the disk wobbles, as it does for a conventional encoder with fixed read stations.

Once the device has been setup as described, it is used just as a conventional incremental encoder. The variations in the detector array signals coming from each head are averaged, counted, and interpreted as angular rotations.

### Advantages Of The Device

The hybrid encoder is modular in construction such that the disk and the encoder body have no direct physical connection. This results in an encoder which is tolerant of external loads. Damage at installation or during operation is therefore less likely than it is for a high resolution conventional encoder. Because the device employs no internal bearings, the reliability of the device is enhanced. The absence of these bearings also eliminates a potential source of contaminants either in the form of lubricants or wear debris.

Because the hybrid encoder uses read stations which employ internal servo controlled actuators, the encoder is actively self-aligning. Thus, warp and wobble in the disk are accommodated. External vibration, which might introduce misalignment between the encoder body and the disk, is also accommodated.

The disk used in the hybrid encoder is of the type used in optical disk drives rather than the photolithographic type used in conventional optical encoders. Thus, two important features are gained. First, because a laser is used to encode the disk, smaller markings may be encoded on the disk. A higher resolution is therefore obtainable for an encoder of a given diameter. As recording techniques and materials are refined in the various types of mass media, this encoder concept may be adapted to the media offering the greatest bit density. So even higher resolutions may be feasible.

The second advantage afforded by using the optical disk along with the associated optics is that the disk is

more tolerant of contamination and physical abuse. This is due to the convergent optical path and the fact that the information layer is within the disk rather than on the surface.

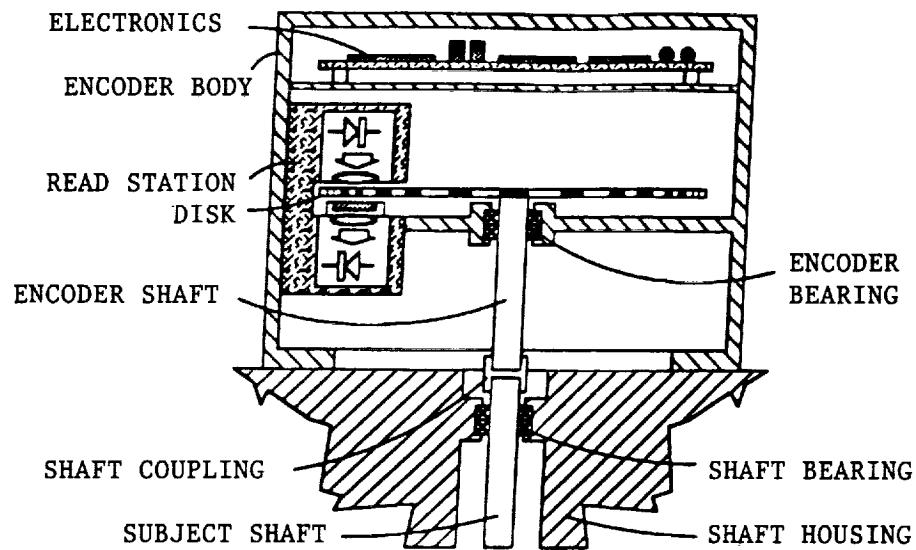
The disk used in the hybrid encoder has a band of concentric tracks, any of which the read station may acquire. Alignment to the target track is achieved automatically using available feedback. Because of this,, the effort required to perform initial alignment and setup of the encoder is greatly reduced [3].

### **CONCLUDING REMARKS**

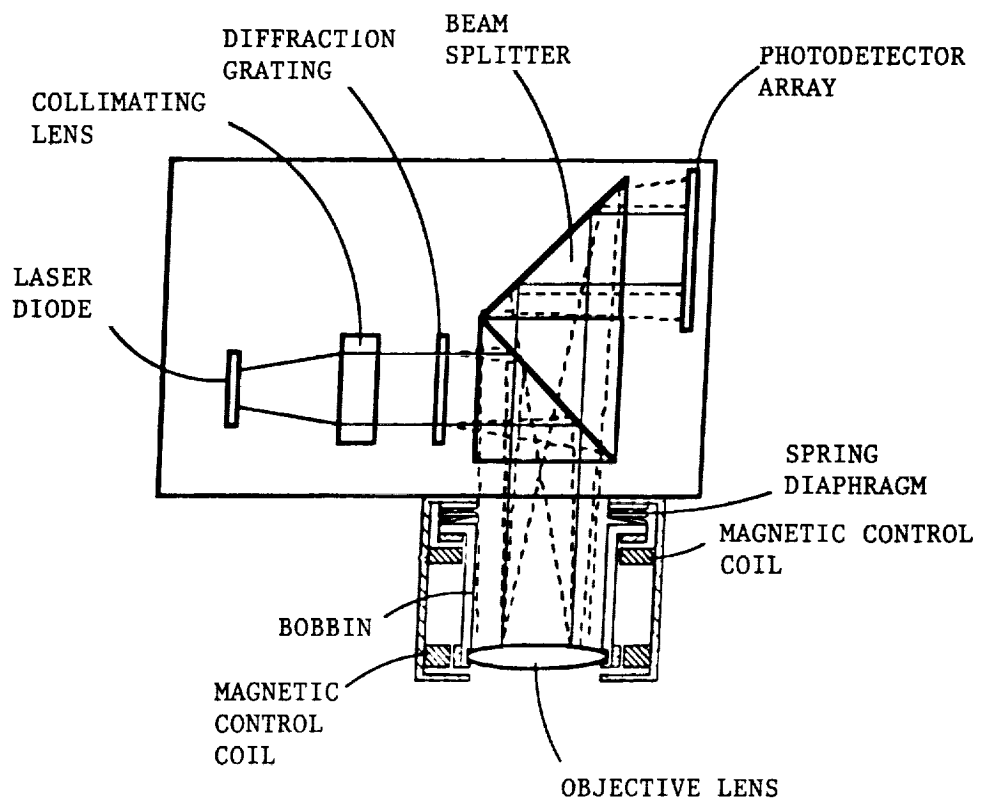
This device shows promise, but requires an investment in time and resources. Hardware experimentation has begun, although it has been on hold for some time. Limited error sensitivity analyses have also been performed, but further study is required.

### **REFERENCES**

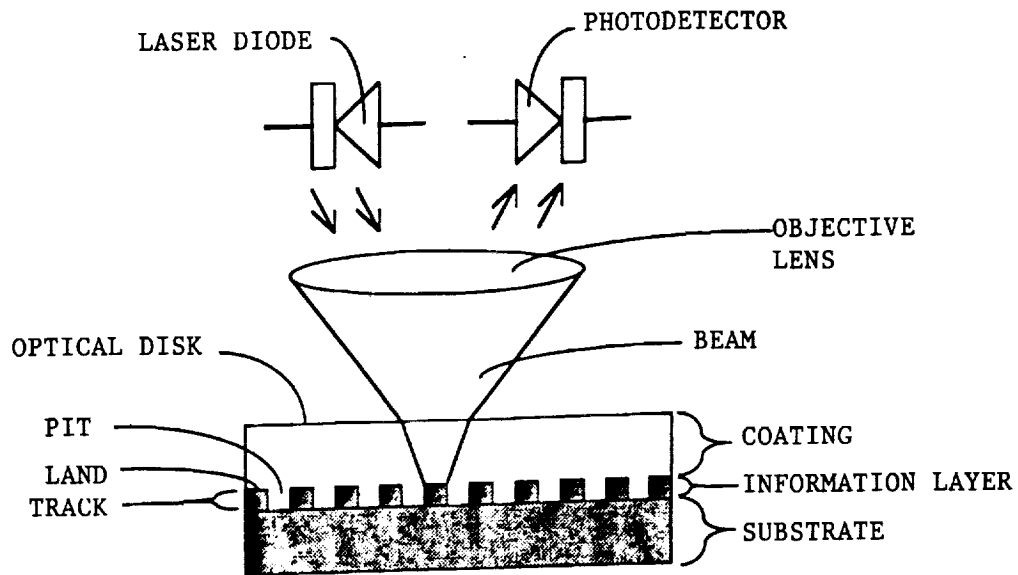
1. Techniques for Digitizing Rotary and Linear Motion. Dynamics Research Corporation, 3rd ed., November 1980.
2. Watkinson, J.: The Compact Disc System. Electronics & Wireless World, January 1985, pp. 69-71.
3. Osborne, Eric P.: Laser Optical Disk Position Encoder with Active Heads. Patent Application: NASA Case No. GSC 13,175-1, 1990.



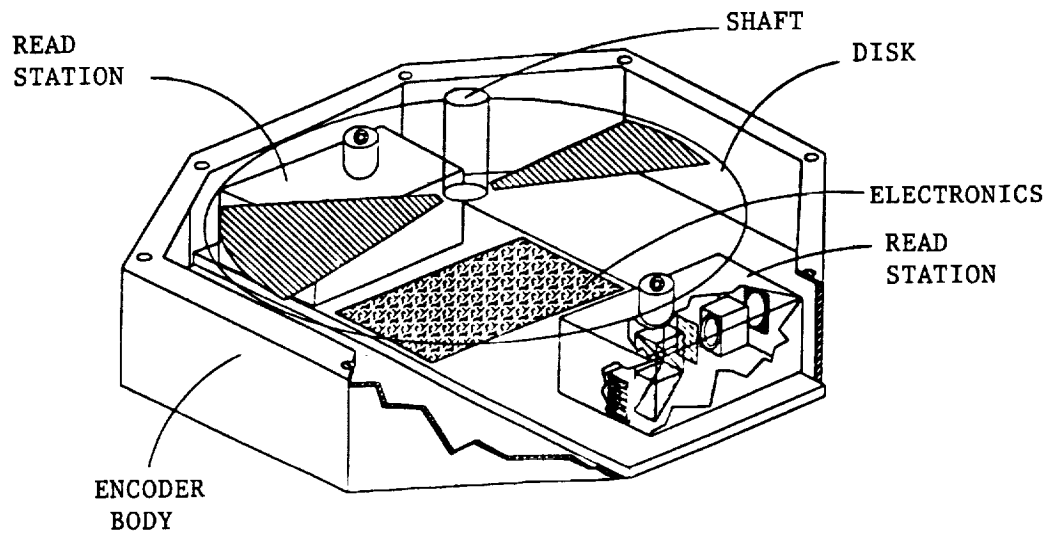
**FIGURE 1 - CONVENTIONAL ENCODER**



**FIGURE 2 - TYPICAL READ STATION**



**FIGURE 3 - BEAM PATH SCHEMATIC**



**FIGURE 4 - ISOMETRIC VIEW OF HYBRID ENCODER**

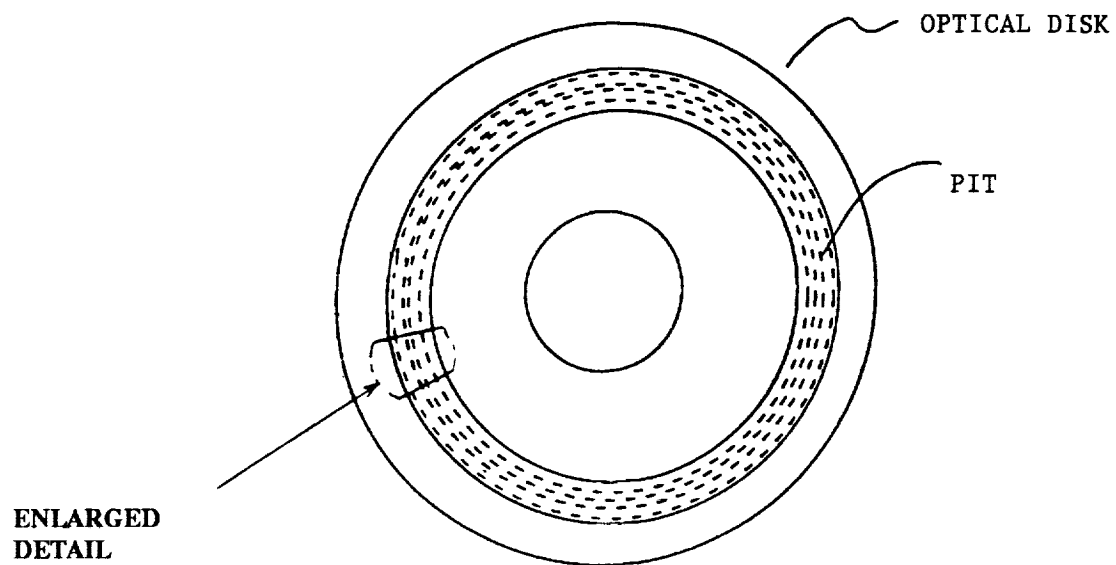
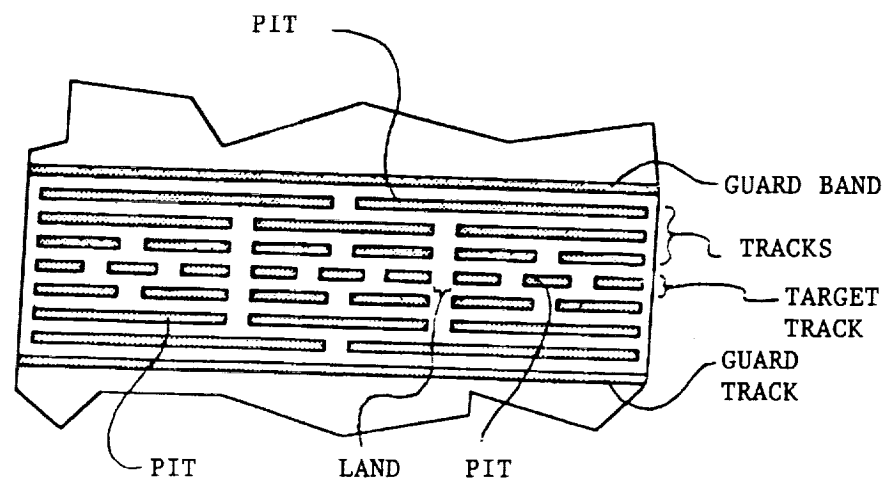


FIGURE 5A



ENLARGED DETAIL

FIGURE 5B

FIGURE 5 - HYBRID ENCODER TRACK ARRANGEMENT



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